Benefits of Addressing HFCs under the Montreal Protocol

June 2012

Stratospheric Protection Division
Office of Atmospheric Programs
Office of Air and Radiation

U.S. Environmental Protection Agency

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EXECUTIVE SUMMARY

Although safe for the ozone layer, the continued emissions of HFCs—primarily as alternatives to ODS but also from the continued production of HCFC-22—will have an immediate and significant effect on the Earth's climate system. Without further controls, it is predicted that HFC emissions could negate the entire climate benefits achieved under the Montreal Protocol. HFCs are rapidly increasing in the atmosphere. HFC use is forecast to grow, mostly due to increased demand for refrigeration and air conditioning, particularly in Article 5 countries. There is a clear connection to the Montreal Protocol's CFC and HCFC phaseout and the increased use of HFCs. However, it is possible to maintain the climate benefits achieved by the Montreal Protocol by using climate-friendly alternatives and addressing HFC consumption.

Recognizing the concerns with continued HFC consumption and emissions, the actions taken to date to address them, the need for continued HFC use in the near future for certain applications, and the need for better alternatives, Canada, Mexico and the United States have proposed an amendment to phase down HFC consumption and to reduce byproduct emissions of HFC-23, the HFC with the highest GWP. The proposed Amendment would build on the success of the Montreal Protocol, rely on the strength of its institutions, and realize climate benefits in both the near and long-term. Table ES-1 displays the projected benefits from the Amendment.

Table ES-1: Estimated Benefits of the Amendment Proposal, at Various Intervals

Cumulative HFC Reductions (MMTCO$_2$eq)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown				
Non-Article 5 Parties	2,200	11,500	25,900	42,100
Article 5 Parties	14	5,000	19,100	42,900
World*	**2,200**	**16,500**	**45,000**	**85,000**
Byproduct Controls				
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World*	**1,000**	**3,000**	**6,200**	**11,300**
World Total *	**3,200**	**19,500**	**51,200**	**96,400**

* World totals may not sum due to rounding.

1. Introduction

This paper presents analysis of potential benefits from globally reducing consumption of hydrofluorocarbons (HFCs) and reducing byproduct emissions of HFC-23. HFCs are a subset of fluorinated greenhouse gases intentionally-made and used in various applications. HFCs are predominantly alternatives to ozone-depleting substances (ODS) being phased out under the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). Recent scientific papers, including a 2009 paper by Velders et al.,[1] a 2011 paper by Gschrey et al.,[2] and a report from the United Nations Environment Programme (UNEP),[3] suggest that HFC use will grow substantially over the next several decades, driven both by increased demand for refrigeration and air-conditioning (in particular but not exclusively in developing countries (hereafter referred to as Article 5 or A5)), and because these substances were developed and are being implemented as alternatives to ODS.

In 1995, HFC emissions constituted approximately 1% of U.S. emissions of the existing basket of covered United Nations Framework Convention on Climate Change (UNFCCC) greenhouse gases (weighted by Global Warming Potential (GWP)).[4] By 2010, HFC emissions had grown to over 2% of the basket of net emissions. If left unaddressed, consumption of HFCs is projected to roughly double by 2020 relative to today, which, if emissions of other greenhouse gases remain about constant, could result in HFCs constituting 3-4% of the basket by 2020. Growth of HFCs is anticipated to continue well beyond 2020 if left unconstrained or weakly regulated. One important study estimates that HFC global emissions could rise to as much as 19% of carbon dioxide equivalent (CO_2eq) emissions by 2050.[5]

UNEP's recent report, *HFCs: A Critical Link in Protecting Climate and the Ozone Layer* concludes HFCs have the potential to substantially influence climate. By 2050, the buildup of HFCs is projected to increase radiative forcing by as much as 0.4 W m^{-2} relative to 2000 and this increase would be as much as one-quarter of the expected increase in radiative forcing from CO_2 buildup since 2000. The abundances of HFCs in the atmosphere are also rapidly increasing. One example is HFC-134a, the most abundant HFC, which has increased by about 10% per year from 2006 to 2010.[6] Global HFC emissions (excluding emissions of HFC-23) increased 8 percent per year from 2004 to 2008. By acting now, UNEP concludes we can avoid an increase in high-GWP HFC emissions that would otherwise offset the climate benefit achieved by the ODS phaseout.[7]

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[1] Velders, G. J. M., Fahey, D. W., Daniel, J. S., McFarland, M., and Andersen, S. O. : The large contribution of projected HFC emissions to future climate forcing, P. Natl. Acad. Sci. USA, 106, 10949–10954, doi:10.1073/pnas.0902817106, 2009. 2091, 2092, 2098, 2108 Accessible at: http://www.pnas.org/content/early/2009/06/19/0902817106.full.pdf+html
[2] Gschrey, B., Schwarz, W., Elsner, C., Engelhardt, R.,: High increase of global F-gas emissions until 2050, Greenhouse Gas Measurement & Management 1, 85-92, 2011.
[3] UNEP, 2011. *HFCs: A Critical Link in Protecting Climate and the Ozone Layer*, United Nations Environment Programme (UNEP), 36 pp. Accessible at http://www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf
[4] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010,* April 15, 2012, EPA Report #430-R-012-001, www.epa.gov/climatechange/emissions/usinventoryreport.html
[5] Velders et al., PNAS, 106, June 2009
[6] UNEP, 2011
[7] Ibid.

HFC emissions also occur during the production of some fluorocarbons. This paper also presents analysis of potential benefits from globally reducing the byproduct emissions of HFC-23 during the production of hydrochlorofluorocarbon (HCFC)-22.

2. Proposed Amendment to Phase Down HFC Consumption and Reduce HFC-23 Byproduct Emissions

The governments of Mexico, Canada, and the United States of America proposed an amendment to the Montreal Protocol to phase down the consumption and production of HFCs and reduce HFC-23 byproduct emissions. Key elements of this Amendment proposal include:

- Lists 21 HFCs including two substances sometimes referred to as hydrofluoro-olefins (HFOs).
- Recognizes that there may not be alternatives for all HFC applications and therefore utilizes a gradual phase-down mechanism with a plateau, as opposed to a phaseout.
- Establishes provisions for developed country (non-Article 5) and developing country (Article 5) phase-down of production and consumption.
    - The baseline for Article 5 countries is calculated based on HCFC consumption and production respectively averaged over years 2005-2008, recognizing there are HFC data limitations in some countries.
    - For non-Article 5 countries, the baseline is determined from a combination of HFC plus 85% of HCFC consumption and production respectively averaged over years 2005-2008.
    - Uses weighting by Global Warming Potential for HCFCs and HFCs.
- Includes provisions to limit HFC-23 byproduct emissions resulting from the production of HCFCs and HFCs beginning in 2016.
- Requires licensing of HFC imports and exports, and bans imports and exports to non-Parties.
- Requires reporting on production and consumption of HFCs, and on HFC-23 byproduct emissions.
- Makes HFC production and consumption and byproduct emissions controls eligible for funding under the Multilateral Fund for the Implementation of the Montreal Protocol (MLF).

3. Proposed Phase-down of HFC Consumption

3.1. Summary of Benefits Analysis

The U.S. Environmental Protection Agency's (U.S. EPA's) benefits analysis of the amendment proposal suggests it would reduce greenhouse gas (GHG) emissions by 96,400 million metric tonnes of carbon dioxide equivalent (MMTCO_2eq) through 2050.

The assumptions used in U.S. EPA's analysis are based on the North American Amendment proposal and assumes a global phase-down of HFC consumption. The analysis assumes the HFC reduction obligations in the proposal by the Mexico, Canada and the United States are met, while all Parties (developed and developing countries) continue to comply with current HCFC phaseout obligations. Although both the HFC proposal and the HCFC controls would be effective simultaneously, individual country conditions and obligations would determine whether transitions in HCFC sectors include an interim step (i.e., HCFC to HFC to low-GWP), occur directly (HCFC to low-GWP), or continue to use fluorocarbons (HCFC to HFC) for the foreseeable future. The estimated cumulative HFC reductions from the phasedown are 2,200 $MMTCO_2eq$ [8] through 2020, and 85,000 $MMTCO_2eq$ through 2050, assuming annual global compliance with the HFC phase-down requirements. As explained in Section 4 below, the estimated cumulative HFC reductions from the control of byproduct emissions of HFC-23 are 1,000 $MMTCO_2eq$ through 2020, and 11,300 $MMTCO_2eq$ through 2050, assuming annual global compliance.

3.2. Assumptions for Establishing the Baseline and Projected Consumption

3.2.1. Baseline

Because HFCs have replaced HCFCs in many applications in some countries, the baseline used by Mexico, Canada and the United States is set using historical information while accounting for this transition. Because HCFC controls for Article 5 countries do not start until 2013 with a freeze followed by a 10% reduction step in 2015, only historical HCFC consumption is used to set the baseline. The baseline for all Parties uses data from the years 2005 through 2008. The baseline for Article 5 countries is calculated as 100% of the average 2005-2008 HCFC consumption. The baseline for non-Article 5 countries is calculated as 100% of the average 2005-2008 HFC consumption plus 85% of the average 2005-2008 HCFC consumption. The formulas to estimate baselines are shown in Table 1.

Table 1: Estimated Baselines

Party	Method	Baseline ($MMTCO_2eq$)
Non-Article 5 Parties	100% HFC + 85% HCFC Consumption, Average 2005-2008	760
Article 5 Parties	100% HCFC Consumption, Average 2005-2008	729
World		**1,489**

3.2.2. Projected Consumption of HCFCs and HFCs

In addition to estimating historical HCFC and HFC consumption, U.S. EPA estimated business-as-usual (BAU) HFC consumption through 2050 to determine the benefits of the proposed phase-down. Such estimates are prepared regionally and aggregated below to reflect Article 5, non-Article 5, and world totals.

[8] The benefit calculations assume participation from all parties to the Montreal Protocol (i.e., global participation), with consumption at the maximum level allowed under the proposed amendment. Other modeling techniques could calculate different benefits. For instance, a different method could be used to analyze what reduction options are available, what benefits they would achieve, and, assuming options are undertaken based solely on cost, the reductions that would be achieved.

Projected Consumption in the United States: HCFCs and HFCs

For estimates of U.S. consumption, U.S. EPA used its Vintaging Model,[9] which tracks and projects past and future use and emissions of chemicals (including HFCs) in products that previously relied on ODS. Although each type of product is modeled separately at its respective growth rates as determined through information relevant to the product type, U.S. EPA projected the U.S. growth of all products at an equal and steady amount beginning in 2030, the date at which ODS consumption in the United States will cease. For this period 2030-2050, U.S. EPA assumed an annual growth rate for each HFC-using product of 0.8%, which equals the approximate population growth rate expected in the United States at that time. Previous sensitivity studies using a 1.8% annual growth rate for 2030-2050 show an approximate 10% increase in cumulative benefits through 2050.

Projected Consumption in Other Countries: HCFCs

HCFC consumption data as reported under Article 7 of the Montreal Protocol are used to determine total GWP-weighted HCFC consumption. Because reports from UNEP and the Ozone Secretariat are in ODP-tonnes, assumptions regarding the mix of HCFCs constituting such ODP-tonne consumption are made for Article 5 countries based on UNEP (2007)[10] and for non-Article 5 countries based on U.S. consumption patterns. Once this breakdown (i.e., HCFC-22, HCFC-141b, HCFC-142b, etc.) is estimated, GWPs in the proposed Amendment, taken from the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4),[11] are used to develop total HCFC consumption in terms of $MMTCO_2eq$.

Projected Consumption in Other Countries: HFCs

HFC consumption was estimated on a country-by-country basis and then aggregated to Article 5 and non-Article 5 regions. To develop the global HFC consumption baseline through 2050, U.S. EPA relied on the approach used to develop two peer-reviewed reports released in 2006: *Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases 1990-2020* (U.S. EPA Report #430-R-06-003)[12] and *Global Mitigation of Non-CO_2 Greenhouse Gases* (U.S. EPA Report #430-R-06-005).[13] This process, as outlined in those reports, generally follows these steps:

1. Gather ODS (i.e., CFC, HCFC, halons, carbon tetrachloride, and methyl chloroform) consumption data as reported under the Montreal Protocol. Data from 1986, 1989 or 1990 are chosen because they pre-date most of the ODS phaseout.[14]

[9] Vintaging Model, 12/16/2009. (This version is used to maintain consistency with past analyses presented to the Montreal Protocol Parties.)
[10] UNEP (2007) "Status/Prospects of Article 5 Countries in Achieving Compliance with the Initial and Intermediate Control Measures of the Montreal Protocol." UNEP/OzL.Pro/ExCom/52/7/Rev.1 9 July 2007.
[11] International Panel on Climate Change (IPCC). 2007. "Climate Change 2007: The Physical Science Basis." Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. September 2007.
[12] http://www.epa.gov/climatechange/economics/international.html#global_anthropogenic
[13] http://www.epa.gov/climatechange/economics/international.html#global_mitigation
[14] If available, 1989 data is used; where 1989 data is not available, the next closest available year's data is used.

2. Split ODS consumption by ODS type into end-use sectors (i.e., refrigeration/air conditioning, aerosols, foams, solvents, and sterilization).
3. Use ODS consumption to estimate HFC consumption by multiplying by the ratio of U.S. HFC consumption for the relevant year to U.S. 1990 ODS consumption. U.S. HFC consumption estimates are generated from U.S. EPA's Vintaging Model as described above.
4. Scale HFC consumption by the region's Gross Domestic Product (GDP) growth relative to the U.S. historical and projected GDP. Data were obtained from the U.S. Energy Information Administration (2008).[15]
5. Apply several adjustment factors to account for country-specific differences in transition pathways:
    a. Apply the later phaseout of ODS for Article 5 countries.
    b. Account for a proportion of natural refrigerants (such as hydrocarbons) in lieu of HFCs in the baseline for all regions except North America.
    c. Account for lower levels of recovery and recycling of refrigerants from small equipment in Article 5 countries and certain eastern European countries.
    d. Account for regional transitions in the foams and fire protection sectors by using results from regional Vintaging Model runs that modeled sector-specific data from both the fire protection industry[16] and the foams industry.[17]
6. Multiply the consumption (i.e., tonnes) by an average GWP to derive GWP-weighted consumption (i.e., $MMTCO_2eq$). The average GWP, which varies by sector, is determined by examining the estimated baseline HFC consumption in the United States in 2012. This year is chosen because the U.S. HFC market is assumed to be relatively mature by this date and, under a BAU scenario, the mix of HFCs, and hence the average GWP, is not expected to change significantly thereafter. For instance, the year 2012 is beyond the recent (January 1, 2010) U.S. and Montreal Protocol HCFC phaseout step.

The procedure outlined above is summarized in Equation 1:

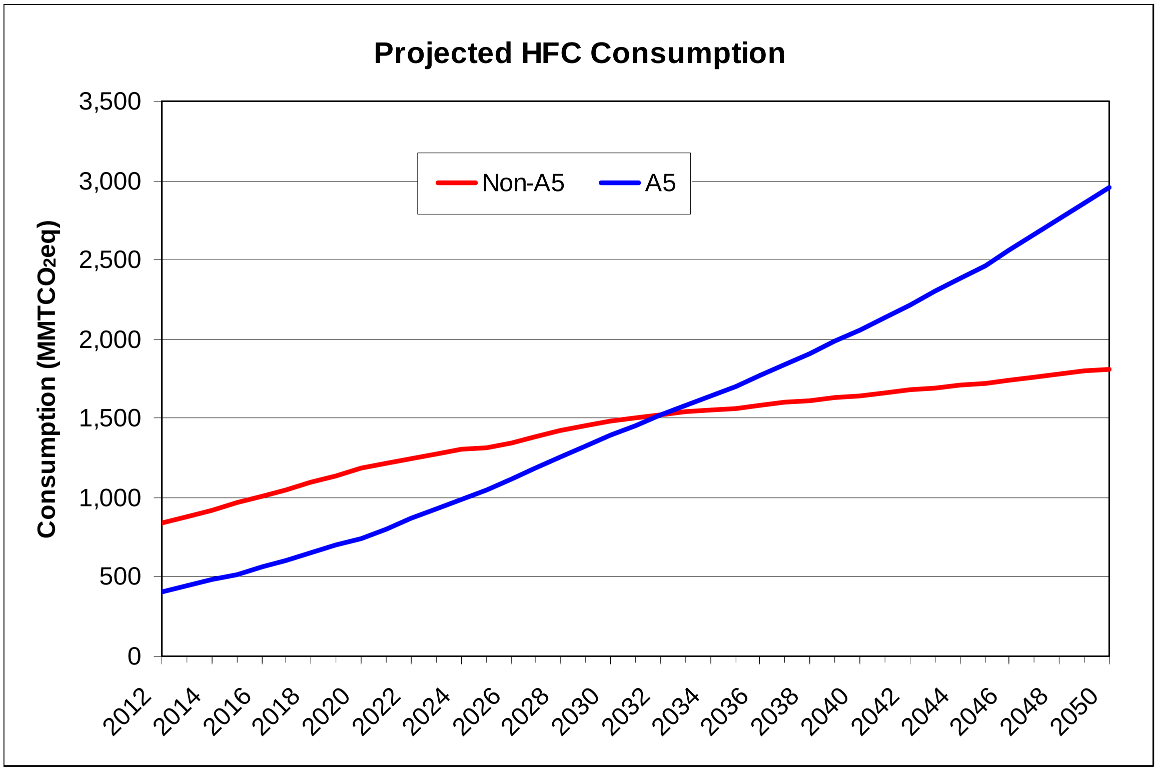
Equation 1: Estimating HFC consumption from ODS consumption data

$$\begin{array}{c}\text{ODS}\\\text{consumption}\\\text{(1989 or as}\\\text{available)}\end{array} \times \begin{array}{c}\text{End Use}\\\text{Percentage}\end{array} \times \frac{\begin{array}{c}\text{HFC consumption}\\\text{(U.S., year)}\end{array}}{\begin{array}{c}\text{ODS consumption}\\\text{(U.S., 1990)}\end{array}} \times \begin{array}{c}\text{Growth and}\\\text{other}\\\text{adjustments}\end{array} \times \begin{array}{c}\text{Average GWP of}\\\text{HFC consumption}\\\text{(U.S., 2012)}\end{array} = \begin{array}{c}\text{GWP-weighted}\\\text{HFC consumption}\\\text{(year)}\end{array}$$

[15] EIA (2008) *International Energy Outlook 2008*. Washington, D.C. Release date: June 2008. Department of Energy/Energy Information Administration-084(2008). At: http://www.eia.doe.gov/oiaf/archive/ieo08/index.html
[16] 2001 Hughes Associates - International Market Share Data
[17] Data provided by Paul Ashford in personal communications with ICF in 2004.

Projected consumption estimates for Article 5 and non-Article 5 are shown in Graph 1 below.

Graph 1. Projected HFC Consumption 2012 Through 2050



3.3. Reduction Scenario and Results

The reduction schedule used for this analysis appears in Table 2 and Graph 2 below. Targets were set by considering the need to achieve real and significant reductions, the likely availability of alternatives, and other obligations under the Montreal Protocol (e.g., HCFC phaseout). Applying the reduction schedule and baselines to the projected consumption developed as described above yields HFC consumption reductions as shown in Table 3. Table 3 estimates the cumulative reductions of HFC consumption for four different time intervals: 2016 to 2020, 2016 to 2030, 2016 to 2040, and 2016 to 2050.

Table 2: Proposed HFC Reduction Schedules

HFC Consumption Reduction Schedule			
Non-Article 5 Parties		Article 5 Parties	
Year	**Cap (% of Baseline)**	**Year**	**Cap (% of Baseline)**
2016	90%	2018	100%
2020	70%	2024	80%
2025	50%	2029	60%
2029	30%	2034	40%
2033	15%	2043	15%

Graph 2. Proposed HFC Reduction Schedule

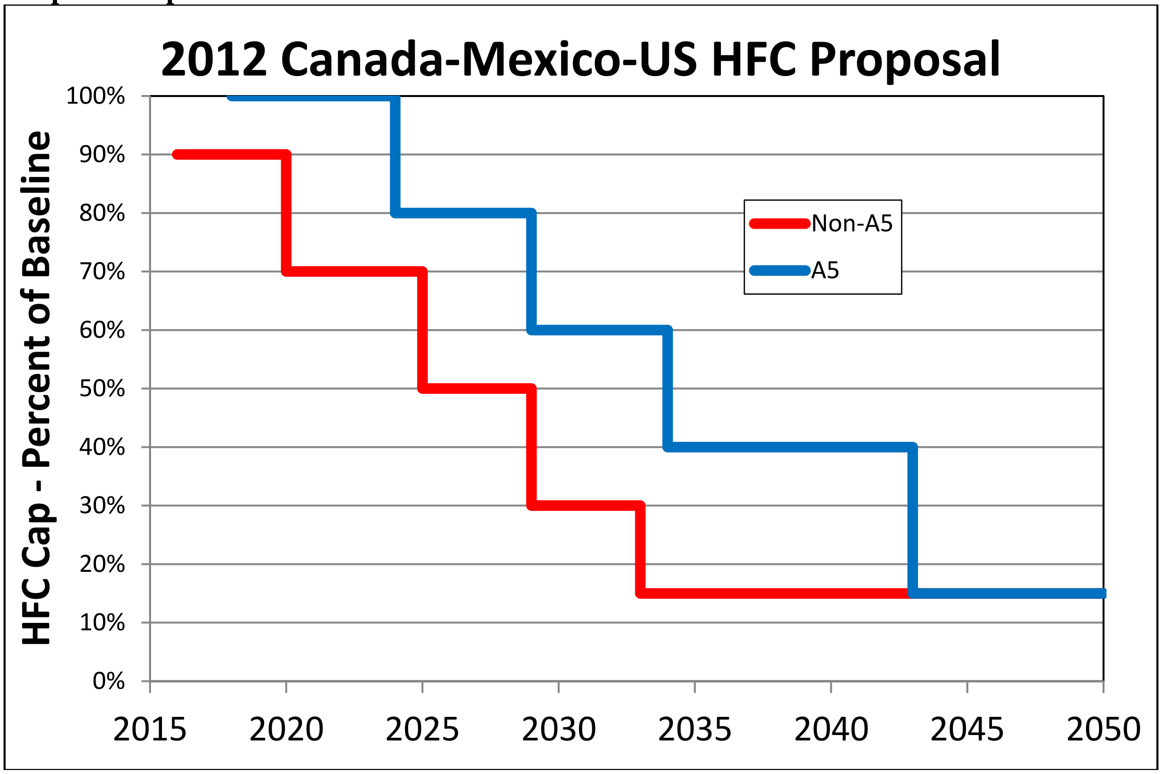


Table 3: Estimated Benefits of the HFC Phasedown, at Various Intervals

Cumulative HFC Phasedown Reductions ($MMTCO_2eq$)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
Non-Article 5 Parties	2,200	11,500	25,900	42,100
Article 5 Parties	14	5,000	19,100	42,900
World*	**2,200**	**16,500**	**45,000**	**85,000**

* World total may not sum due to rounding.

3.4. Availability of Alternatives for Meeting the Reduction Schedule

In many ways, the current availability of substitutes (in this case for HFCs) is similar to the availability of CFC substitutes at the 1987 signing of the Montreal Protocol, and similar to when the Parties agreed to phase out HCFCs – in all cases, some alternatives were (or are) known but not for all applications.

As part of the U.S. ozone layer protection program, the U.S. EPA established the regulatory Significant New Alternatives Policy (SNAP) program in 1994. The SNAP program ensures a smooth and timely transition from ODS to a variety of alternatives across major industrial, commercial, and military sectors. The SNAP program's findings are relevant globally and can be used by countries as they consider transitioning to alternatives. The SNAP program provides a broad menu of options that includes HFCs with a range of GWPs as well as non-HFC options. As the SNAP menu continues to expand, more low-GWP and no-GWP alternatives have been added.

U.S. EPA analyzed certain sector-specific, technically- and economically-viable mitigation options for HFCs. The most promising options to reduce HFC consumption fall into these broad categories:

- Substituting HFCs with low-GWP or no-GWP substances in a variety of applications (where safety and performance requirements can be met);
- Implementing new technologies that use, at installation and/or over the lifetime of the equipment, no or significantly lower amounts of HFCs; and,
- Various process and handling options—including the principles of refrigerant recovery and management implemented during the CFC phaseout—that reduce consumption during the manufacture, use, and disposal of products that contain or use HFCs.

SNAP continues to identify substitutes – for ODS as well as HFCs – that offer lower overall risks to human health and the environment. The risk factors considered include:

- Ozone Depletion Potential (ODP);
- Global Warming Potential (GWP);
- Flammability;
- Toxicity;
- Contributions to smog;
- Aquatic and ecosystem effects; and,
- Occupational health and safety.

To date, U.S. EPA has reviewed over 400 substitutes in the refrigeration and air conditioning; fire suppression; foam blowing; solvent cleaning; aerosols; adhesives, coatings, and inks; sterilants; and tobacco expansion sectors. Most substitutes have been found acceptable, although in some cases restrictions are applied to protect the environment and human health. Across all sectors, roughly one-third of the substitutes reviewed contain HFCs. For the refrigeration and air conditioning sector, HFCs now dominate. However, the SNAP program has issued several rulemakings, and is currently considering a number of other such rulemakings and projects, that have and will continue to provide additional low-GWP or no-GWP options including hydrocarbons and low-GWP HFOs.

Information on existing and potential options to reduce HFCs can be found in Tables 4 through 6. For some subsectors additional information also is available on U.S. EPA’s website, as discussed below.

Table 4. HFC Substitutes by Sector: Aerosols, Foams, Fire Suppression & Solvents

End-Use		Substitute or Mitigation Strategy	Change in CO_2e Where Adopted*	Years Until Available**
Aerosols	Non-Medical	Replace HFC-134a with HFC-152a	91%	Available Now
		Hydrocarbons	~100%	Available Now
		Not-in-Kind (pumps, roll-ons, etc.)	100%	Available Now
		HFO-1234ze(E)	95.2 to 99.6%	Available Now
	Medical	Dry Powder Inhalers	100%	Available Now
		Injections / Tablets	100%	10+
Fire Suppression	Total Flooding	Inert Gases	100%	Available Now
		Water Mist	100%	Available Now
		Fluorinated Ketone	99.97%	Available Now
	All	Other Low-GWP Substances	~90%	10+
Foam Blowing	Various	Hydrocarbons	~100%	Available Now
	XPS	CO_2	99.9%	<5
	Spray	H_2O	100%	<5
	Appliance, XPS, Spray	HFO-1234ze(E)	99.4 to 99.6%	<5
		HFO-1336mzz(Z), -1233zd(E)	99.0 to 99.3%	<5
	Appliance Foam	Capture / Destruction at End-of-Life (EOL)	~90%	Available Now
	Construction Foam	Capture / Destruction at EOL	~90%	10+
Solvents	Electronics & Precision Cleaning	Aqueous & Semi-Aqueous	100%	Available Now
		Hydrofluoroethers (HFEs)	82 to 96%	Available Now
		-1233zd(E)	99.6%	<5

* Indicates the reduction achieved where applied. For example, replacing HFC-134a with HFC-152a yields a 91% reduction in consumption (in CO_2-equivalent terms). However, the substitute or mitigation strategy may not be applicable across the entire end-use.

** Key to time-frames

Available Now: option applied in significant amounts; regional and product type variations may exist
<5 Years: option in the early deployment stage and/or SNAP acceptability determination made or proposed
<10 Years: option known to be under development and/or logical extension of other known options
10+ Years: option not known to be under development; more research and testing required

Table 5. HFC Substitutes by Sector: Air Conditioning

End-Use	Substitute or Mitigation Strategy	Change in CO_2e Where Adopted	Years Until Available
All End Uses	Refrigerant Management: Recovery, Reclamation and Destruction	10 to 100%*	Available Now
	Leak Repair	10 to 100%*	Available Now
Auto A/C	Enhanced HFC-134a Systems	50%	Available Now
	HFO-1234yf, CO_2, HFC-152a	91.3 to 99.9%	<5
Bus, Train A/C	HFO-1234yf, CO_2	99.7 to 99.9%	<5
Residential & Commercial A/C, Chillers	Microchannel Heat Exchangers	35 to 50%	Available Now
	HFC-32, Low-GWP Blends	50 to 90%	<10
Room A/C	Hydrocarbons, CO_2, HFO-1234yf	~100%	Available Now to <5
Dehumidifiers			

* Wide range indicates the wide range of practices across different end-uses and institutional behaviors.

Table 6. HFC Substitutes by Sector: Refrigeration

End-Use	Substitute or Mitigation Strategy	Change in CO_2e Where Adopted	Years Until Available
All End Uses	Refrigerant Management: Recovery, Reclamation and Destruction	10 to 100%*	Available Now
	Leak Repair	10 to 100%*	Available Now
Supermarkets	Low Charge / Low Leak Technologies (e.g., Cascade or Secondary Systems)	90 to 100%	Available Now
	Low-GWP Blends	50 to 90%	Available Now to <10
Chillers, Cold Storage	Ammonia	100%	Available Now
	Low-GWP Blends, HFOs	50 to 99.3%	Available Now to <10
Home Refrigerators/ Freezers	Hydrocarbons, CO_2, HFOs	99.7 to ~100%	Available Now
Stand-Alone Commercial Refrigerators/ Freezers			Available Now
Beverage Coolers			Available Now
Vending Machines			<5
Ice Makers			<5
Transport Refrigeration	Hydrocarbons, Ammonia, Low GWP Blends	50 to 100%	<10

* Wide range indicates the wide range of practices across different end-uses and institutional behaviors.

It is clear that many options exist across all major sectors to reduce, or even eliminate, the use of HFCs. Some of these options are available today, meaning they could be used to meet HCFC phaseout obligations while at the same time contributing to the proposed HFC reductions. While low-GWP alternatives already exist for many end-use applications, additional research may be required to find alternatives for some important applications, such as large residential and light-commercial air conditioning (i.e., unitary air conditioners and multi-splits).

3.5. Transitioning to Low-GWP Alternatives

A detailed analysis of how Parties might meet the proposed reduction schedule has not been performed, as that would depend on national circumstances and preferences. However, many types of transitions can be foreseen and are shown schematically in Figures 1 through 5 below. For example, the mobile air conditioning industry is poised to introduce HFO-1234yf or CO_2 in new vehicles to meet regulations in Europe; these same technologies could be used elsewhere. In May, 2010, U.S. EPA issued standards for GHG emissions from passenger cars and other light-duty vehicles for model years 2012 through 2016. That regulation included an option for car manufacturers to earn credit toward their company's GHG emission standards by switching from the current automotive refrigerant, HFC-134a, to a refrigerant with a lower GWP. Some car manufacturers may find a switch to HFO-1234yf or another low-GWP refrigerant to be a reasonable and cost-effective part of a compliance strategy to meet their company's emission standards. For example, General Motors previously announced they intend to start manufacturing some models using HFO-1234yf in their 2013 model year, to be built in 2012 in the United States.[18] General Motors has now confirmed they have started charging cars with HFO-1234yf.

Several options in foam-blowing, including hydrocarbons and HFOs, also offer an opportunity for non-Article 5 countries to reduce HFC consumption, and for Article 5 countries to move directly from HCFCs in certain applications. Many types of hermetic air-conditioning and refrigeration equipment—including domestic refrigerators, vending machines, and bottle coolers—are becoming available worldwide with low-GWP alternatives in lieu of HCFC-22, HFC-134a and other high-GWP chemicals. Over the past few years, a number of Article 5 countries have included a range of lower GWP alternatives in their HCFC Phaseout Management Plans (HPMPs). For example, rather than using R-410A (an HFC blend with a GWP of 2,088), Indonesia is using R-32 (an HFC with a GWP of 675) for certain air conditioning applications. China included R-290 (propane) for a certain percent of window units. They agreed to convert 18 production lines to R-290.

U.S. EPA has developed a series of sector-specific fact sheets to provide more current information on low-GWP or no-GWP alternatives. Six fact sheets covering commercial refrigeration, domestic refrigeration, motor vehicle air conditioning, unitary air-conditioning, transport refrigeration, and construction foam are currently available on our website at: www.epa.gov/ozone/intpol/mpagreement.html. Figures 1 through 5 illustrate the transition pathways that have occurred and are emerging as CFCs and HCFCs are being phased out and a combination of HFCs and low-GWP alternatives are being used.

The following examples illustrate the varied paths countries and companies have taken as they move out of ODS and into HFCs and low-GWP options. In some cases, such as motor vehicle air conditioning (MVAC) (Figure 1), industry moved to one option (HFC-134a), but is now in a position to introduce various low-GWP alternatives. In other cases, such as domestic

[18] Automotive Engineering Online, Cadillac XTS first U.S. car with R-1234yf A/C, 14 February 2012. Accessible at http://www.sae.org/mags/AEI/10663

refrigeration and unitary air conditioning (Figures 2 through 4), some companies moved directly from ODS to low-GWP options while others first moved to HFCs and are now considering the low-GWP options.

Figure 1. Refrigerant Transition in the (MVAC) End-Use (Passenger Vehicles and Light Trucks)

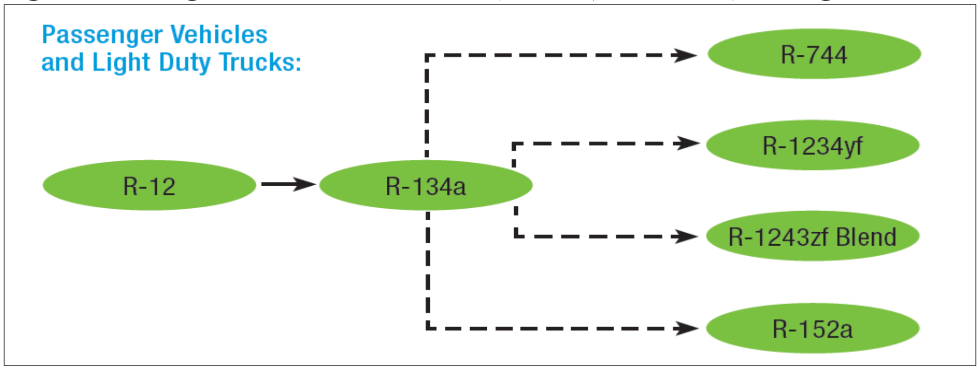


Figure 2. Refrigerant Transition in the Domestic Refrigeration End-Use

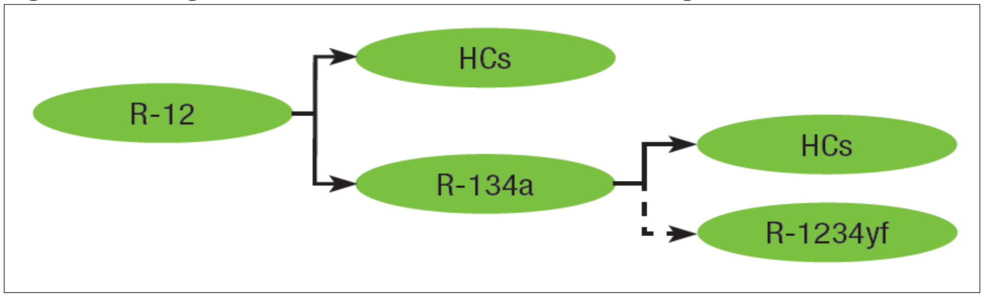


Figure 3. Blowing Agent Transition in the Domestic Refrigeration End-Use

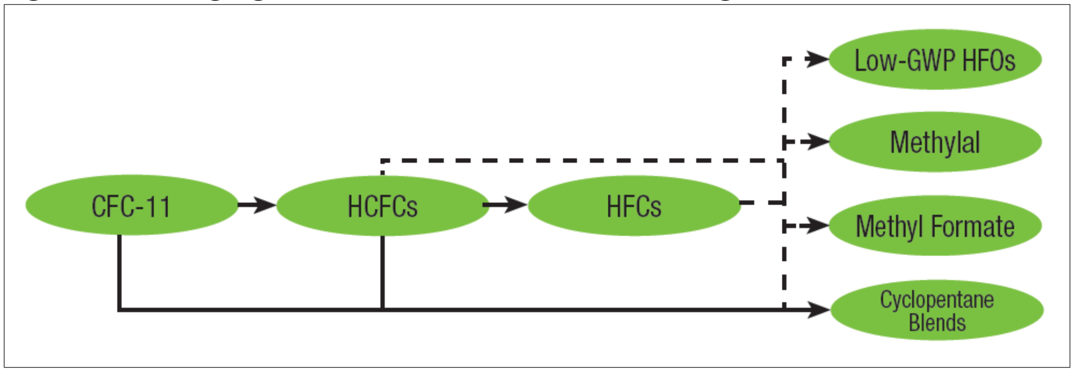


Figure 4. Refrigeration Transition in the Unitary Air Conditioning End-Use

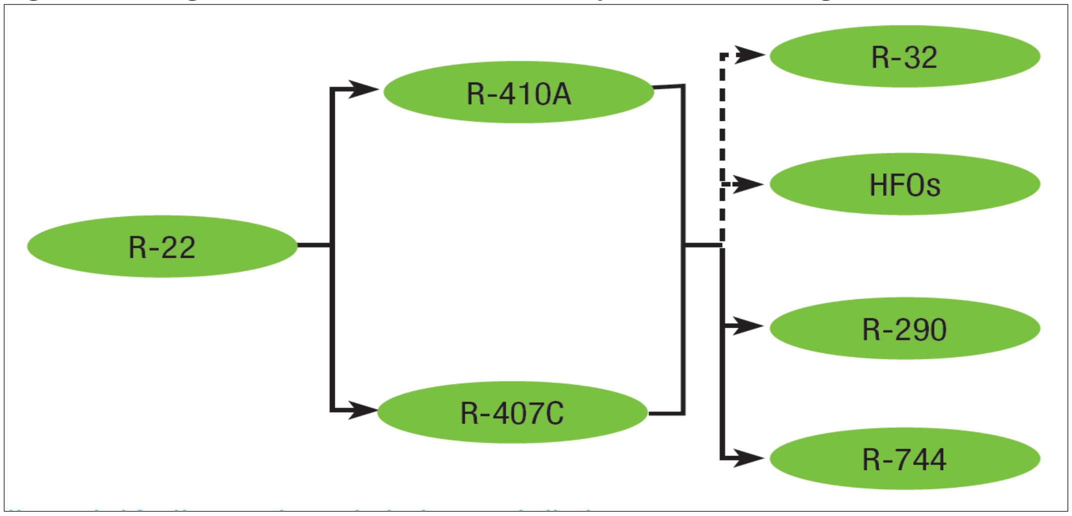
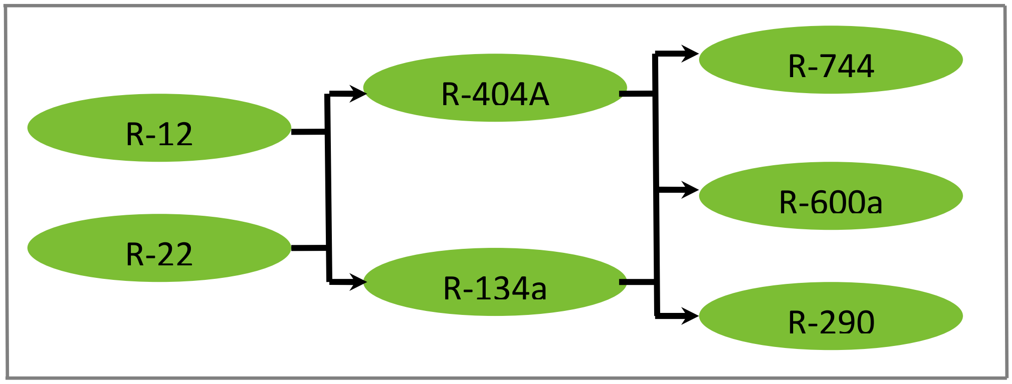
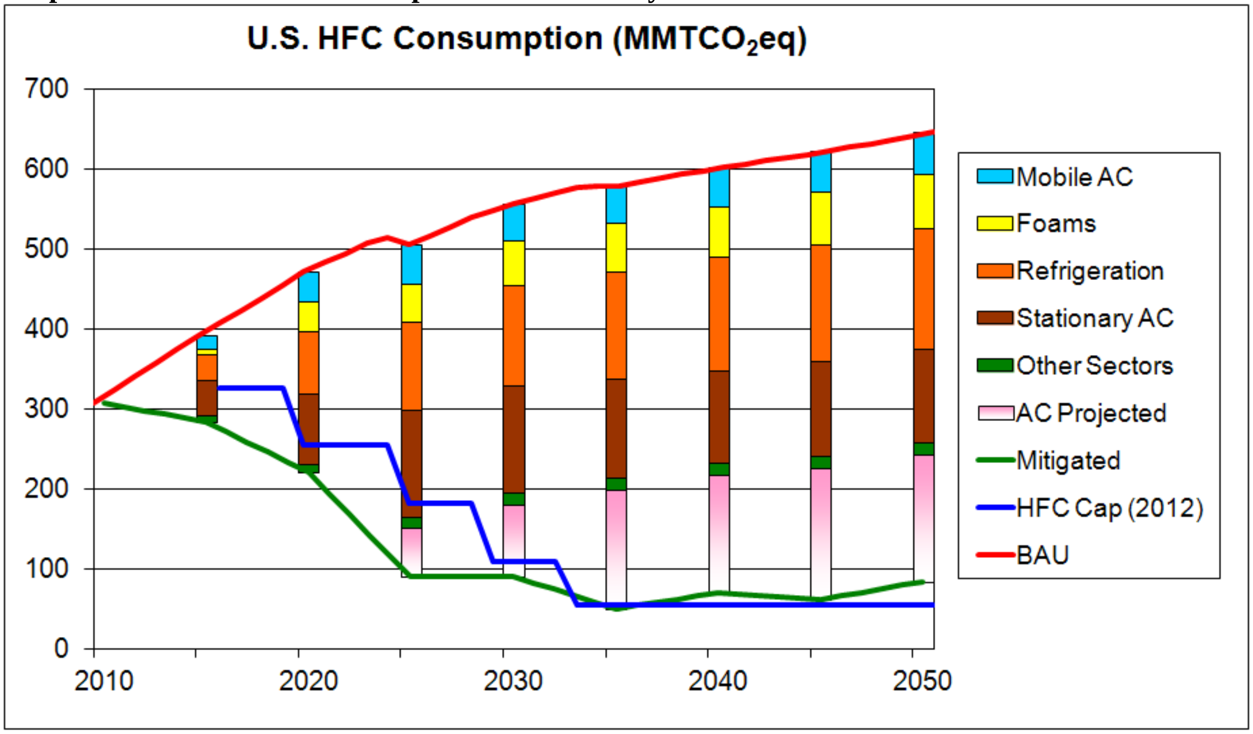


Figure 5. Refrigerant Transition in the Commercial Refrigeration End-Use (Stand-Alone Equipment)



These five and 12 other diagrams are available in the six sector fact sheets listed above.
U.S. EPA performed a preliminary analysis of how HFC consumption could be reduced in the United States. Multiple alternatives were analyzed, including many of those highlighted in Tables 4 through 6 and in the transition pathways in Figures 1 through 5. As shown in Graph 3, a multi-sector approach could be used by the United States to reduce HFC consumption from the increasing business-as-usual projection to levels necessary to meet the proposed amendment. It is assumed here that some HFC use will remain beyond 2033, in compliance with the 15% level called for in the proposed Amendment. In this example, it is clear that the majority of reductions come from the refrigeration and air conditioning sectors, but that reductions from the other sectors also play an important part. Existing options could help the United States meet its obligations in the near term; however, some projected alternatives need to be developed and implemented in the next decade or so, and potentially other or better reduction alternatives need to be found, for compliance in the long term.

Graph 3. Potential HFC Consumption Reductions by Sector for the United States



3.6. Case Studies in the Transition to Low-GWP Alternatives

3.6.1. Transitions at the Regional and National Levels

The following are summaries of transitions certain nations or regions have taken to adopt low-GWP alternatives in specific sectors. These three examples show how national circumstances can be taken into account while adopting low-GWP alternatives. Example national and regional level transition summaries are available from the U.S. EPA sector fact sheets.

Unitary Air Conditioning: China's Experience
China manufactures half of the world's 50 million mini-split air conditioner (AC) systems annually. It's the largest manufacturer of AC equipment in the developing world. A significant portion of production is for the export market—China supplies nearly 85% of the window, wall, and mini-split AC imports to the United States, and is also a major supplier to Europe, Asia and elsewhere. While R-22 continues to dominate unitary AC domestically, China manufactures both R-22 and R-410A units. The R-410A units are in high demand as exports to developed countries. China has commercialized room ACs with R-290 and is researching unitary AC products with R-32.

Construction Foams: Europe's Experience
The European Union phased out HCFCs in construction foam by the early 2000s and much of the building/construction sector transitioned directly to hydrocarbons (HCs), having used these blowing agents in other products since the early 1990s. Some smaller companies, as well as those making foams with stringent end-use flammability standards, used HFCs. Through product

development, most of these standards now can be met with HC-based foams, and HFC use has diminished. The only exception is the spray foam application, which still relies primarily on HFCs.

Refrigerated Transport Trucks and Trailers: Norway's Experience
In 2007, liquid CO_2 refrigerant-based cryogenic systems were introduced into Norway's road transport refrigeration market. Cryogenic truck and trailer systems use liquid CO_2 for refrigeration to minimize environmental impact and noise while providing high reliability and lower maintenance.

In 2011, approximately 16% of new refrigerated truck and trailer systems sold in Norway were equipped with cryogenic refrigeration systems. One of Norway's largest food distributors has committed to making cryogenic system-equipped vehicles the standard for all of their future purchases. In addition, a major manufacturer of cryogenic systems has partnered with one of Norway's largest refrigerant suppliers to provide CO_2 filling stations across the country. Cryogenic systems are currently used in other European countries (e.g., Sweden, Denmark, Finland, France, the Netherlands, and Germany), and are being piloted in the United States. Use of liquid CO_2 refrigerant-based cryogenic systems is expected to expand further in the future, particularly in Western Europe.

Commercial Refrigeration Systems: Australia's Experience
Australia's major supermarkets have committed to reducing commercial refrigeration emissions through lower GWP refrigerants, advanced refrigeration technology, and innovative store designs. The supermarket chains determined that half of their emissions (in CO_2eq terms) are from refrigeration systems. Losses from HFC refrigerants account for a significant portion of these emissions. Supermarkets are incorporating CO_2 cascade and transcritical refrigeration systems to meet their target reductions in CO_2eq. emissions. Shifting from HFCs to CO_2 can reduce the carbon footprint of supermarkets by 25%. Since 2008, at least 23 stores have implemented this new technology. Australia has evaluated the benefits of new technologies and provided assistance to update supermarket refrigeration equipment.

3.6.2. Transitions at the Company and Project Levels

Some examples of specific company actions to adopt low-GWP alternatives are discussed below. These illustrate how individual companies are already moving towards a low-GWP future, often without any regulatory requirements to do so. In addition, some specific case studies of projects are shown below as examples of actions to adopt environmentally sound alternatives.

Hydrocarbon Ice Cream Freezers: Unilever's Experience
In 2000, Unilever, an international ice cream company that owns about 2 million ice cream freezers throughout the world, pledged that it would not buy ice cream freezers that were charged with HFC refrigerants after 2005 in countries where legal and commercially-viable alternatives were available.[19] After deciding that hydrocarbons were the most viable option, the company had

[19] Australian Institute of Refrigeration, Air Conditioning, and Heating (AIRAH). 2007. "Natural Refrigerant Case Studies." Available online at: http://www.environment.gov.au/atmosphere/ozone/publications/pubs/refrigerants-guide.pdf.

50 R-290 ice cream freezers manufactured for the 2000 Sydney Olympics. Testing of this equipment confirmed that the R-290 cabinets would be able to maintain the correct temperatures even under severe use conditions. It was also found that the cases used considerably less energy than the comparable freezers using R-404A (an HFC blend). By mid-2008, there were 270,000 such units in use worldwide;[20] and by 2009, Unilever had alone placed over 400,000 HC ice-cream coolers around the world, including South Africa, China, Europe, Brazil and the United States.[21]

Carbon Dioxide Vending Machines: Sanyo's Experience

Sanyo has produced CO_2 compressors since 2001, originally developed for Heat Pump Water Heaters. Using this technology, Sanyo developed the first CO_2 vending machine, which was field tested in February 2004 in Australia. Results from these test showed that the CO_2 system consumed 17% less energy compared to the comparable HFC-134a system during the summer season. Beginning in 2005, CO_2 vending machines began being sold in Japan and now represent a significant and growing portion of the Japanese market—estimated at more than 30,000.[22,23] Coca-Cola has committed to using CO_2 as the refrigerant in vending machines carrying their products; they have shipped units to Canada and are test-marketing units in the United States.

Transcritical Carbon Dioxide Supermarkets: Sobeys' Experience

Since the first supermarket transcritical CO_2 system installation in 2002—at a Coop store in Lestans, Italy—around 1,200 such systems have been installed across Europe.[24] The technology is now spreading to North America. Sobey's, Canada's second largest food retailer, installed its first transcritical CO_2 system in July 2006 and has plans to implement the technology in all of its 1,300 stores in 15 years. In one study of three transcritical stores compared to 22 conventional stores using R-507 (an HFC blend), Sobey's found the transcritical system to require 18% to 21% less energy. Also, Sobey's did not experience significant problems with the systems despite operating during the higher-than-normal temperatures experienced in Quebec in the summers of 2010 and 2011.[25]

Low-GWP HFC

In 2011, the Indonesia Ministry of Environment and Ministry of Industry; the Japan Ministry of Economy, Trade and Industry (METI); Daikin and Panasonic, and with support of the United Nations Development Programme (UNDP) reached an agreement to introduce HFC-32 air conditioners in the Indonesian market. Since then, Fujitsu General, Hitachi, and Toshiba have

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[20] Gerwen, Rene Van, Alan Gerrard, and Fabio Roberti. 2008. "Ice Cream Cabinets Using Hydrocarbon Refrigerant: From Technology Concept to Global Rollout." Prepared for the 8th IIR Gustav Lorentzen Conference on Natural Working Fluids. Available online at: http://www.unilever.com/images/Ice%20Cream%20Cabinets%20Using%20a%20Hydrocarbon%20Refrigerant%20-%20From%20Technology%20Concept%20to%20Global%20Rollout_tcm13-262015.pdf.

[21] Greenpeace. 2010. "Cool Technologies: Working without HFCs." Available online at: http://www.hysave.com/wp-content/uploads/2010/07/COOLING-WITHOUT-HFCs-June-2010-Edition.pdf.

[22] Sanyo Electric Co. 2008. "CO_2 Vending Machines." Technical Meeting on HCFC Phase-Out.

[23] Greenpeace. 2010. "Cool Technologies: Working without HFCs." Available online at: http://www.hysave.com/wp-content/uploads/2010/07/COOLING-WITHOUT-HFCs-June-2010-Edition.pdf.

[24] ACR News. "UK a leader in transcritical CO2 refrigeration." Available online at: http://www.acr-news.com/news/news.asp?id=2767&title=UK+a+leader+in+transcritical+CO2+refrigeration.

[25] Supermarket News, 2012. "Refrigeration Systems Chillin' with Carbon Dioxide." Available online at: http://supermarketnews.com/technology/refrigeration-systems-chillin-carbon-dioxide.

also joined the effort. This will allow for Indonesia and potentially other Article 5 countries to take advantage of this newer technology. The partners indicate that these new air conditioners also will be highly energy-efficient.[26]

Ammonia
Supervalu opened an ammonia-based refrigeration system in their Albertsons store in Carpinteria, California in 2012, the first in the United States. The Carpinteria Albertsons store is a remodeled unit that doubled in size to 40,000 square feet. The store had used HCFC-22 in a conventional direct expansion (DX) refrigeration system, which was replaced with one that uses ammonia as the primary refrigerant with CO_2 for medium-temperature cases, and a combined cascade and DX system for low-temperature cases.[27]

Liquid Propane Extruded Polystyrene (XPS) Foam: Egypt's Experience
The United Nations Development Programme (UNDP) implemented a project in Egypt to phase out the use of ODS in XPS foam. Although butane and isobutane were considered for the conversion, ultimately liquid propane gas was used due to its lower cost and because the gas could be obtained easily for this project. Local contractors were hired to complete the conversion. The conversion resulted in improved quality of the foam; the foam had a softer touch (which consumers preferred) and was less brittle. Its density was also reduced, which improved the market position of the company. The project performed a safety audit that concluded that plant was operated safely with use of liquid propane gas as the blowing agent.

4. Byproduct Emissions of HFC-23

4.1. Proposed Amendment and Current Mitigation Activities

The Mexico, Canada, and U.S. Amendment proposal includes provisions that limit HFC-23 byproduct emissions resulting from the production of HCFCs and HFCs beginning in 2016. HFC-23 is a potent greenhouse gas that is 14,800 times more damaging to the Earth's climate system than carbon dioxide. HFC-23 is a known byproduct from the production of HCFC-22. HCFC-22 is used primarily as a refrigerant and as a feedstock for manufacturing synthetic polymers. HCFC-22 is an ODS; non-feedstock production of it is scheduled for phaseout by 2040 under the Montreal Protocol. However, given the extensive use of HCFC-22 as a feedstock, its production is projected to continue indefinitely. While a small amount of HFC-23 is used predominantly in plasma-etching processes in semiconductor manufacturing, as a fire suppressant, and either neat or as a blend component in cryogenic refrigeration, the vast majority of HFC-23 produced is not used and is either emitted, captured or destroyed. Recent studies[28] indicate that HFC-23 emissions continue to increase in developing countries despite global efforts to curb emissions.

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[26] JARN News, August 2011 "Indonesia-Japan HFC-32 Partnership Targets Room Air Conditioner Market" Available online at: http://www.ejarn.com/news.asp?ID=16248
[27] Supermarket News June 2012" Supervalu Pleased With Ammonia Refrigerant" Available online at: http://supermarketnews.com/technology/supervalu-pleased-ammonia-refrigerant
[28] *Montzka et al., "Recent increases in global HFC-23 emissions". Geophysical Research Letters, December 2009*

Nearly all producers in non-Article 5 countries have implemented process optimization and/or thermal destruction to reduce HFC-23 emissions. For example, U.S. EPA worked in partnership with production facilities located in the United States to develop and implement technically feasible, cost-effective processing practices or technologies to reduce HFC-23 emissions from the manufacture of HCFC-22. Since 2010, emissions of HFC-23 from the production of HCFC-22 must be reported to USEPA as part of the Greenhouse Gas Mandatory Reporting Rule (40 CFR Part 98). U.S. EPA's report, *Global Mitigation of Non-CO_2 Greenhouse Gases*[29], analyzes technology options that can be deployed in both Article 5 and non-Article 5 countries.

Currently, some HFC-23 emissions are mitigated through Clean Development Mechanism (CDM) projects using destruction technologies, namely thermal oxidation or plasma arc. The CDM allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one ton of CO_2. However, not all HCFC-22 facilities are eligible to earn credits under CDM; therefore a number of facilities may not have emission reduction technology installed. There is uncertainty regarding the future of CER credits from destroying HFC-23 as well as in the future of CDM and compliance carbon markets in general. For example, in 2011, the European Commission formally adopted a ban on HFC-23 credits in the European Union's Emissions Trading System (ETS) beginning January 1, 2013. While ETS will no longer accept these credits, individual countries set their own domestic policies. Many countries have announced that they too will not accept credits generated from HFC-23 destruction. It is unclear how offset credits or emissions reduction credits from HFC-23 destruction may be accounted for in the future, therefore, in order to conservatively estimate benefits, this analysis assumes business as usual within CDM.

Approximately 43 production lines within 26 existing HCFC-22 facilities were identified in Article 5 countries.[30] There are about 23 production lines within 17 facilities in Article 5 countries with CDM Projects approved or awaiting approval. An estimated 20 production lines are assumed to not currently have emission control technologies installed. Given that CDM only covers some facilities, this analysis assumes that the provisions apply to all countries and that controls to mitigate (i.e., destroy) HFC-23 emissions are installed in all production lines that do not already have an approved project under the CDM to control emissions of HFC-23.

The timelines for the crediting periods also varies for each project; they are either a one-time 10-year crediting period or a 7-year renewable crediting period for up to 21 total years. Below is a schematic of the time periods. Table 8 illustrates the timeline of the 18 CDM projects[31] and each project's renewal process, if any. The first crediting year of current CDM projects was 2004; the last crediting year will be 2029.

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[29] *Global Mitigation of Non-CO_2 Greenhouse Gases (USEPA 430-R-06-005, June 2006).*Available at: http://www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf

[30] "Summary of Information Publicly Available on Relative Elements of the Operation of Clean Development Mechanisms and the Amounts of HCFC-22 Production Available for Credits" by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Fifty-seventh Meeting, Montreal, 30 March – 3 April 2009. Available at: http://www.multilateralfund.org/files/57/5762.pdf and "Preliminary Data on the HCFC Production Sector in China" Excel worksheet accessible online at: https://www.ungm.org/Notices/Item.aspx?Id=14001

[31] Note that two CDM projects in China apply to the same facility. Hence, these 18 projects represent 17 facilities.

Table 8: Timeline for CDM Projects Crediting Periods

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4.2. Benefits from Byproduct Controls

Benefits were calculated with UNEP reported and projected data for HCFC consumption, feedstock production estimates (Montzka, 2009), publicly available data on individual CDM Projects (accessible at: http://cdm.unfccc.int/), and data from the MLF Secretariat.[32] Using the

[32] "Summary of Information Publicly Available on Relative Elements of the Operation of Clean Development Mechanisms and the Amounts of HCFC-22 Production Available for Credits" by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Fifty-seventh Meeting, Montreal, 30 March – 3 April 2009. Available at: http://www.multilateralfund.org/files/57/5762.pdf

data from the CDM, the annual amount of CERs for each project, which is based on IPPC Second Assessment Report (SAR) GWP values, is transformed to reflect the updated GWPs in AR4 and the Amendment proposal. As CDM projects go offline, the benefits are included in the cumulative total. Benefits from production lines not covered under CDM, from both Article 5 and non-Article 5 countries, are assumed to accrue beginning in 2016.

A number of assumptions were made to estimate the benefits: HCFC-22 production for feedstock is projected to increase at a rate of 5% per year through 2050 (based on Montzka, 2009); HCFC-22 production for consumption (i.e., non-feedstock uses) is derived from HCFC consumption data for 2009 through 2012[33] and adjusted to reflect the HCFC phasedown; and, the baseline (i.e., without the amendment proposal) fraction of HFC-23 produced per tonne of HCFC-22 is estimated to be 3% in Article 5 countries based on CDM methodologies and 1% in non-A5 countries. Once the total HCFC-22 production is estimated from adding together the adjusted consumption plus projected feedstock, the total is multiplied by the estimated fraction of HFC-23 produced per tonne of HCFC-22. That result is then multiplied by the GWP of HFC-23 and finally divided by 1,000,000 to yield the benefits for that year in MMTCO_2eq. Results are shown in Table 9 below.

Table 9: Estimated Benefits of HFC-23 Byproduct Emission Controls, at Various Intervals

Cumulative HFC-23 Byproduct Emission Reductions (MMTCO_2eq)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World* Byproduct Controls	**1,000**	**3,000**	**6,200**	**11,300**

* World total may not sum due to rounding.

The amendment proposed by Canada, Mexico and the United States includes provisions to reduce emissions of HFC-23 from HCFC-22 production; however, the obligations do not apply to emissions from production lines that have an approved project under CDM to control HFC-23 emissions so long as those emissions are covered by and continue to generate emissions reduction credits under a CDM project. If a facility does not have a CDM project because either it is not eligible or the project has expired, then the obligations would apply and funding from the MLF could be available.

5. Summary

The Montreal Protocol has been an unparalleled environmental success story. It is the only international agreement to achieve universal ratification. It has completed an enormous task in the phaseout of CFCs and halons—chemicals that had become pervasive in multiple industries. It established a schedule to phaseout the remaining important ODS (namely, HCFCs). Under the

[33] "Updated Model Rolling Three-Year Phase-Out Plan: 2011-2013 (Decision 59/5), Table 7." Document 62/7 by Executive Committee of the Multilateral Fund for the Implementation of the Montréal Protocol, Sixty-second Meeting, Montreal, 29 November – 3 December 2010. Available at: http://www.multilateralfund.org/files/62/6207.pdf

Montreal Protocol, Article 5 and non-Article 5 countries together have not only set the ozone layer on a path to recovery by mid-century but have reduced greenhouse gases by over 11 Gigatons CO_2eq per year, providing an approximate 10-year delay in the onset of the effects of climate change.[34]

This legacy is now at risk. Although safe for the ozone layer, the continued emissions of HFCs—primarily as alternatives to ODS but also from the continued production of HCFC-22—will have an immediate and significant effect on the Earth's climate system. Without further controls, it is predicted that HFC emissions could negate the entire climate benefits achieved under the Montreal Protocol. HFCs are rapidly increasing in the atmosphere. HFC-use is forecast to grow, mostly due to increased demand for refrigeration and air conditioning, particularly in Article 5 countries. There is a clear connection to the Montreal Protocol's CFC and HCFC phaseout and the increased use of HFCs. However, it is possible to maintain the climate benefits achieved by the Montreal Protocol by using climate-friendly alternatives and addressing HFC consumption.

Recognizing the concerns with continued HFC consumption and emissions, the actions taken to date to address them, the need for continued HFC use in the near future for certain applications, and the needed for better alternatives, Canada, Mexico and the United States have proposed an amendment to phase down HFC consumption and to reduce byproduct emissions of HFC-23, the HFC with the highest GWP. The proposed Amendment would build on the success of the Montreal Protocol, rely on the strength of its institutions, and realize climate benefits in both the near and long-term. Table 10 displays the projected benefits from the Amendment.

Table 10: Estimated Benefits of the Amendment Proposal, at Various Intervals

Cumulative HFC Reductions ($MMTCO_2eq$)				
Party	**2016 to 2020**	**2016 to 2030**	**2016 to 2040**	**2016 to 2050**
HFC Phasedown				
Non-Article 5 Parties	2,200	11,500	25,900	42,100
Article 5 Parties	14	5,000	19,100	42,900
World*	**2,200**	**16,500**	**45,000**	**85,000**
Byproduct Controls				
Non-Article 5 Parties	300	900	2,000	3,800
Article 5 Parties	700	2,100	4,200	7,500
World*	**1,000**	**3,000**	**6,200**	**11,300**
World Total *	**3,200**	**19,500**	**51,200**	**96,400**

***** World totals may not sum due to rounding.

Taken together, the suite of known alternative chemicals, new technologies, and better process and handling practices can significantly reduce HFC consumption and emissions in both the near and long term, while simultaneously completing the HCFC phaseout. Although there is much work to do to fully implement these chemicals, technologies and practices, and some unknowns still remain, the industries currently using HCFCs and HFCs have proven through the ODS phaseout that they can move quickly to protect the environment.

[34] Velders, G. J. M., Andersen, S. O., Daniel, J. S., Fahey, D. W., and McFarland, M.: The importance of the Montreal Protocol in protecting climate, P. Natl. Acad. Sci. USA, 104, 4815-4819, Accessible at: http://www.pnas.org/content/104/12/4814.full.pdf+html